Handbook of Research on Agent-Based Societies: Social and Cultural Interactions

Goran Trajkovski
Laureate Education Inc., USA

Samuel G. Collins
Towson University, USA
Chapter XXI
Emergent Reasoning Structures in Law

Vern R. Walker
Hofstra University, USA

ABSTRACT

In modern legal systems, a large number of autonomous agents can achieve reasonably fair and accurate decisions in tens of thousands of legal cases. In many of those cases, the issues are complicated, the evidence is extensive, and the reasoning is complex. The decision-making process also integrates legal rules and policies with expert and non-expert evidence. This chapter discusses two major types of reasoning that have emerged to help bring about this remarkable social achievement: systems of rule-based deductions and patterns of evidence evaluation. In addition to those emergent structures, second-order reasoning about legal reasoning itself not only coordinates the decision-making, but also promotes the emergence of new reasoning structures. The chapter analyzes these types of reasoning structures using a many-valued, predicate, default logic – the Default-Logic (D-L) Framework. This framework is able to represent legal knowledge and reasoning in actual cases, to integrate and help evaluate expert and non-expert evidence, to coordinate agents working on different legal problems, and to guide the evolution of the knowledge model over time. The D-L Framework is also useful in automating portions of legal reasoning, as evidenced by the Legal Apprentice™ software. The framework therefore facilitates the interaction of human and non-human agents in legal decision-making, and makes it possible for non-human agents to participate in the evolution of legal reasoning in the future. Finally, because the D-L Framework itself is grounded in logic and not on theories peculiar to the legal domain, it is applicable to other knowledge domains that have a complexity similar to that of law and solve problems through default reasoning.
INTRODUCTION

The logical structure of legal reasoning, and especially its second-order reasoning about the reasoning process itself, is a primary mechanism by which new legal rules and new plausibility schemas emerge, and through which such rules and schemas adapt to the nuances of legal cases. This reasoning structure not only coordinates the efforts of numerous autonomous agents, but also promotes the emergence and evolution of new reasoning structures by responding to the tremendous variability provided by individual legal cases. This chapter describes the Default-Logic (D-L) Framework, which accurately models the logical structure of legal reasoning in actual legal cases. Moreover, it is the logical structure of legal reasoning itself, and not any particular set of rules within the legal knowledge domain, that creates this evolutionary mechanism. This means that the evolutionary mechanism captured by the D-L Framework can operate in domestic, foreign and international legal systems; that non-human autonomous agents can participate in this evolution, interacting with human agents; and that similar reasoning structures can operate in many knowledge domains other than law.

Legal reasoning is a distinctive method of reasoning that has emerged because of adherence to the rule of law. The rule of law requires that similar cases should be decided similarly, that each case should be decided on its merits, and that decision-making processes should comply with all applicable legal rules. One safeguard for achieving these fundamental goals is to make the reasoning behind legal decisions transparent and open to scrutiny. If the legal rules and policies are the same between cases, and the evidence and reasoning in particular cases are publicly available and subject to scrutiny, then the legal decisions in those cases are more likely to be evidence-based and consistent. Transparency makes the decisions less likely to be merely subjective, and more likely to have an objective rationale. An important means of achieving the rule of law, therefore, is articulating and scrutinizing the various elements of the reasoning exhibited in legal cases. Such reasoning involves interpreting constitutions, statutes, and regulations, balancing legal principles and policies, adopting and refining legal rules, adapting those rules to particular cases, evaluating the evidence in each case, and making ultimate decisions that are based on all of these elements.

Legal decision-making today requires many agents performing many different tasks. As the number and diversity of legal cases has increased, and the legal issues in those cases have become more specialized, it has become necessary to distribute the functions needed for optimal decision-making over more and more agents. First, these agents include the specialists in the law itself – the lawmakers (legislators, regulators, and judges), the law-appliers (such as judges and administrative personnel), and the advocates using the law (the lawyers representing parties). Such agents, either individually or in groups, establish the legal rules (e.g., by enacting statutes or issuing regulations), clarify their meaning (e.g., when deciding motions), and ensure that the rules are applied in appropriate cases (e.g., by advocating for particular outcomes, rules and policies). Second, there are the agents (witnesses) who supply the evidence needed to apply the legal rules accurately. Some witnesses have personal knowledge of disputed issues of fact. Other witnesses are experts who have scientific, technical, or other specialized knowledge that is relevant in particular cases – for example, knowledge about forensic science, product testing, medical care or engineering. Such agents supply the evidence needed to apply the legal rules accurately. Third, there are agents who act as the “factfinders.” Depending upon the nature of the proceeding, a jury, judge, or administrative official listens to the witnesses, reads the relevant documents, evaluates all of the evidence, and decides what that evidence establishes as the “facts” for legal purposes. In modern legal systems, with tens of thousands of legal cases, a very large number of autonomous human agents participate, and they together achieve reasonably fair and accurate decisions. This achievement is possible because the reasoning in those cases is organized and supervised under the rule of law; the law, evidence and reasoning are transparent and publicly available; and the decision-making processes are open to scrutiny.

This chapter examines the logical structure of the reasoning involved in such cases, with particular
attention to those structures that have emerged and evolved to help achieve consistency and accuracy. Following a brief background discussion and a summary of the major issues and problems, the chapter describes the elements of the D-L Framework, which has been developed to model the important structures of the reasoning. The next section uses that framework to describe the two basic types of reasoning that have emerged in law: systems of rule-based deductions and patterns of evidence evaluation. The D-L Framework can also model another distinctive feature in legal reasoning: second-order reasoning about the reasoning process itself. The chapter discusses modeling such second-order reasoning using the D-L Framework. This sets up a general discussion of the emergence of reasoning structures or patterns in law. The chapter ends with a conclusion and a suggestion about future research directions.

**BACKGROUND**

The practical nature of legal reasoning renders traditional deductive logic not particularly useful as a modeling framework. Legal reasoning is fundamentally practical in at least three ways. First, legal reasoning is action-oriented – its purpose is to evaluate the justification for governmental action or inaction. Legal reasoning determines whether a statute has been validly enacted, whether an administrative rule should be enforced, and whether a court should impose a sentence on a criminal defendant or order a civil defendant to pay compensation to a plaintiff. Second, legal reasoning and decision-making occur in real time and are constrained by limited resources, including incomplete information. It is a species of decision-making under uncertainty (Kahneman, Slovic & Tversky 1982; Morgan & Henrion 1990). Within the time and resource constraints, those engaged in legal reasoning must determine the appropriate legal rules, evaluate the evidence, decide whether the evidence is complete enough and the residual uncertainty is acceptable, and arrive at an ultimate decision. Third, legal reasoning is practical in the sense that it must always balance the “epistemic objective” of law against the applicable “non-epistemic objectives” (Walker 2003). The epistemic objective in law is to make findings of fact that are as accurate as possible under the circumstances, while basing those findings on the limited evidence that is available. Law aims at truth, but the findings must be reasonably inferred from the evidence. Weighed against this pursuit of truth are numerous non-epistemic objectives – such as ensuring procedural fairness to parties, improving administrative efficiency, or achieving other governmental goals (e.g., an adequate supply of electric power or economic efficiency within securities markets). Each institution of government balances these objectives differently. Legal reasoning, therefore, is practical because it is oriented toward decisions and actions, it occurs under constraints of limited resources and incomplete information, and because it must always balance epistemic and non-epistemic objectives.

Modeling the distinctive reasoning structures that have emerged within this practical context requires a broad view of “logic” as the study of “correct reasoning,” including theories and methods for distinguishing correct from incorrect reasoning (Copi & Cohen 1998). Traditional deductive logic is not a particularly useful framework for modeling legal reasoning because traditional logic is designed to capture the deductive structure of mathematics. More useful in law are recent developments in logic, such as informal logic (Hitchcock & Verheij 2006; Walton 1996, 2002), abductive logic (Josephson & Tanner 1994), and nonmonotonic logic (Brewka, Dix & Konolige 1997; Kyburg & Teng 2001; Levi 1996; Prakken 1997), as well as decision theory, risk-benefit analysis, and risk analysis.

The D-L Framework discussed in this chapter models legal reasoning as an application of default reasoning. Default reasoning uses presumptive inference patterns, together with the available evidence, to warrant defeasible conclusions about possible actions (Besnard 1989; Brachman & Levesque 2004; Brewka, Dix, & Konolige 1997; Josephson & Tanner 1996; Kyburg & Teng 2001; Levi 1996; Pollock 1990; Prakken 1997; Toulmin, Rieke, & Janik 1984; Walton 1996, 2002). Such reasoning patterns possess four important characteristics. First, default reasoning is practical, providing a reasonable basis for decisions and actions. Such reasoning is also dynamic, because the evidence can change over
Emergent Reasoning Structures in Law

time, as can the degree of support from the evidence to the conclusion. Also, multiple parties can participate interactively in the reasoning process. Third, default reasoning is defeasible, meaning that new evidence or a re-analysis of old evidence can defeat an earlier conclusion or undermine its evidentiary support (Pollock & Cruz 1999; Prakken 1997; Walton 2002). Nevertheless, in the absence of such defeating considerations, default reasoning is presumptively valid – that is, it is reasonable to treat the (provisional) conclusion as being probably true (Walton 2002). The D-L Framework introduced here builds these four characteristics into its logical model.

The D-L Framework also has many points of congruence with the extensive research into legal reasoning from the perspective of artificial intelligence (AI). The prominent role of rules in the D-L Framework is in keeping with the “rule-based reasoning” (RBR) approach in AI research (Branting 2000; Rissland 1990). Other portions of the D-L Framework weigh policy arguments or relevant factors, and are related to the AI interest in reasoning by analogy to case precedents, called “case-based reasoning” (CBR) (Branting 2000; Ashley & Rissland 2003; Rissland 1990). AI researchers have also combined these two approaches into hybrid systems (Branting 2000; Prakken & Sartor 1997; Rissland 1990). Tree structures, which are central to the D-L Framework, are commonly used in AI (Branting 2000; Ashley & Rissland 2003; Prakken, Reed & Walton 2003). Moreover, AI researchers have investigated the use of “argumentation schemes” from informal logic, which bear some loose resemblance to plausibility schemas in the D-L Framework (Prakken & Sartor 2004; Prakken, Reed & Walton 2003; Walton 1996). Plausibility schemas are nevertheless unlike argumentation schemes in important respects (Walker 2007a, 2007c). Finally, the Decision Apprentice™ software developed by Apprentice Systems, Inc. incorporates the D-L Framework and successfully applies it to law in the application called Legal Apprentice™ (for details, visit www.apprenticesystems.com).

There are also isolated pockets of theoretical work on legal reasoning methods that provide useful input to the D-L Framework. For example, within research using traditional legal methods, there are studies of the probative value of the forensic sciences (Faigman, Kaye, Saks & Sanders 2002), and research into general patterns of evidence evaluation (Anderson, Schum & Twining 2005; Kadane & Schum 1996; Schum 1994). There is also extensive case law and commentary on when expert opinions are valid enough to be admissible as evidence – for example, under the U.S. Supreme Court’s trilogy of cases, Daubert v. Merrell Dow Pharmaceuticals, Inc., 509 U.S. 579 (1993); General Electric Co. v. Joiner, 522 U.S. 136 (1997); Kumho Tire Co. v. Carmichael, 526 U.S. 137 (1999). Legal reasoning is also examined as such in the context of legal writing (Neumann 2005) and skills training for lawyers (Krieger & Neumann 2003). Moreover, the logic of legal reasoning is studied within particular legal areas, such as tort law (Porat & Stein 2001; Walker 2004) or international trade law (Walker 1998, 2003). Fields outside of law have also studied aspects of legal reasoning, such as psychological research on juries (Hastie 1993) or research in rhetoric (Saunders 2006; Ross 2006). The D-L Framework, however, incorporates insights from these various areas of inquiry into a single, integrated model for legal reasoning as a whole. It also captures the emergent structures of legal reasoning.

Finally, it is essential that the D-L Framework accurately, adequately and efficiently models actual reasoning in actual legal cases. It is the great variety of legal cases, with the hierarchies of legal decision-makers overseeing the reasoning and the extensive documentation of that reasoning, that creates an evolutionary environment. That evolutionary structure refines legal concepts and patterns of reasoning, and adapts them to solving legal problems (Walker 1999, 2007b). These evolutionary forces make it likely that the reasoning patterns that do emerge and evolve are both useful and normative. This evolutionary aspect of legal reasoning necessitates empirical research into the actual balances between epistemic and non-epistemic objectives struck in particular legal areas.

**SUMMARY OF MAJOR ISSUES AND PROBLEMS**

This chapter models legal knowledge, but the modeling framework is applicable to decisional knowl-
Emergent Reasoning Structures in Law

edge in any domain that has similar engineering problems (Russell and Norvig 2003; Singh, Rao, and Georgeff 1999). The major problems in this and similar domains are:

• Accurately capturing the detailed knowledge of the domain, using structures that are suited to that knowledge and to the practice of using that knowledge to solve problems in that domain;
• Integrating expert and non-expert knowledge into a single practical model;
• Applying the knowledge model to solve the next problem;
• Evolving and adapting the knowledge model over time, on the basis of experience with solving problems; and
• Coordinating the use of such knowledge among autonomous agents (both human and non-human) and among different problem sets over time.

The D-L Framework captures the detailed knowledge of the legal domain, and shows how the emergent structures of legal reasoning can help to solve these engineering problems in law and in other knowledge domains.

The DEFAULT-LOGIC FRAMEWORK

The Syntax, Ontology, and Semantics of the Default-Logic Framework

Because of the highly pragmatic nature of legal reasoning, and because the reasoning structures have emerged and evolved over time within the law, logical models of those structures must be developed empirically. It is important, for example, to empirically abstract the logic of reasoning in particular legal areas, such as tort law (Walker 2004) or international trade disputes (Walker 1998, 2006), or the logic of general concepts found across all legal areas, such as the concept of standard of proof (Walker 1996). Only then can a formal model represent those structures that are actually used and useful, and accurately capture legal reasoning as it actually occurs in particular cases. The D-L Framework described in this chapter has been developed in this way. It incorporates some but not all of the logical elements found in traditional predicate logic, and also includes additional elements not found in that logic. It includes only those logical structures actually used and useful in legal reasoning.

The knowledge-capture environment of the D-L Framework can be either textual or graphical, but the graphical syntax is very intuitive for human agents to use. The Decision Apprentice™ software uses Microsoft Office Visio™ as a graphical environment for capturing legal rules. The software builds the knowledge model as the user selects, drags, and connects Visio shapes. The software turns these shapes into “smart shapes” that represent the elements of the syntax—objects with various attributes that allow only combinations of elements that are syntactically acceptable. Figure 1 shows representative shapes for the D-L ontology, and illustrates which combinations of shapes are permissible.

The ontology and Semantics for the D-L Framework are as follows:

• **Proposition:** The informational content of a declarative sentence or clause, which can be meaningfully assigned either a truth-value or a plausibility-value. Examples are: “The defendant is a citizen of the United States” and “Jessica Jones is liable to the plaintiff for battery.” The Decision Apprentice™ shape representing a proposition is shown in Figure 1. A proposition whose active value in a line of reasoning is its truth-value is called simply a proposition, to distinguish it from an evidentiary assertion. The border of the shape is a solid line. By contrast, a proposition whose active value in a line of reasoning is its plausibility-value is called an “evidentiary assertion” or simply an “assertion,” to distinguish it from a proposition whose active value is its truth-value. The Decision Apprentice™ shape for an evidentiary assertion has as its border a dashed line, to indicate that its operative attribute is its plausibility-value.

  o The truth-value of a proposition is an attribute taking one of three values: “true / undecided / false.”
Emergent Reasoning Structures in Law

Figure 1. Illustrative Decision Apprentice™ Shapes for Selected Elements of the D-L Framework

Unanalyzed Proposition:

The defendant is liable to the plaintiff for battery.

Analyzed Proposition:

The defendant is liable to the plaintiff for battery.

Unanalyzed Assertion:

Most witnesses are truthful under oath.

Analyzed Assertion:

Most members of category A are also members of category B.

Implications and Implication Tree (Operating on Truth-Values):

This proposition states the conclusion.

Unless

AND

This proposition states a conjunctive condition.

OR

This proposition states a disjunctive condition.

This proposition states a disjunctive condition.

Assertions in a Schema (Operating on Plausibility-Values):

This assertion states a possible conclusion.

This states a rebutting assertion.

This states an undercutting assertion.

This assertion states information about a definite subject.
The plausibility-value of an assertion is an attribute taking a value from a plausibility scale. Plausibility scales can have any number of values, either qualitative or quantitative. For example, a qualitative plausibility scale might be ordinal and have five values (such as “highly plausible / somewhat plausible / undecided / somewhat implausible / highly implausible”) or seven values (such as “highly plausible / very plausible / somewhat plausible / undecided / somewhat implausible / very implausible / highly implausible”). By contrast with these qualitative scales, mathematical probability provides an infinite-valued quantitative plausibility scale, using the set of real numbers between zero and one, and having values such as 0.56.

A proposition or an evidentiary assertion can be either unanalyzed or analyzed into its predicate-subject structure (see Table 1 for illustrations).

**Subject:** An object, property, situation or event referred to in a proposition, and about which the proposition makes a statement. In the Decision Apprentice™ software, the shape representing a subject can be inserted into a proposition shape, as shown in Figure 1. A “predicate” is not a separate element or shape, but merely the remainder of a proposition excluding its subjects. A predicate functions as a propositional schema that generates meaningful propositions when the appropriate number of subjects are supplied (e.g.: “… is a citizen of …”; “… is liable to … for battery”) (Chierchia & McConnell-Ginet 2000; Copi & Cohen 1998; Larson & Segal 1995; Rodes & Pospesel 1997; Saeed 2003; Sainsbury 1991). In the D-L Framework, it may not be useful to identify and represent every subject in a proposition—only those that play an important referring role in the legal analysis.

- A subject can be a definite subject—that is, a specific individual named by a proper name or a definite description (e.g.: Jessica Jones; the defendant).
- A subject can also be a group or class whose members are identified solely by one or more attributes (e.g.: Americans over age 50; tort cases filed this year in U.S. courts).

**Implication:** A complex proposition (conditional proposition) consisting of one or more propositions as conditions and a single proposition as a conclusion, in which the truth-value of the conclusion is determined by the truth-values of the conditions. In the D-L Framework, the conclusion is placed at the top and its conditions are placed on a lower level, with the conditions connected to the conclusion by “implication arrows” running from the conditions to the conclusion, usually mediated by a truth-value connective (see Table 1 for illustration).

**Plausible inference:** A complex proposition (conditional assertion) consisting of one or more evidentiary assertions as conditions and a single evidentiary assertion as a conclusion, in which the positive plausibility-value of the conclusion is determined by the plausibility-values of the conditions. In the D-L Framework, the conclusion is placed at the top and its conditions are placed on a lower level, with the conditions connected to the conclusion by “implication arrows” running from the conditions to the conclusion, usually mediated by a plausibility connective.

**Logical connective:** An operator that mediates between the conditions and conclusion of an implication or plausible inference, and which specifies a formula for assigning a truth-value or plausibility-value to the conclusion as a function of the truth-values or plausibility-values of the conditions (see Table 1 for illustrations). Logical connectives fall into two major categories—those operating on truth-values and those operating on plausibility-values.

**Truth-value connectives:** The D-L Framework primarily uses three truth-value connectives:

- **Conjunction (“and”):** A connective specifying that the truth-value of the conclusion is “true” if all of the truth-values of the conjunctive conditions are “true” (Copi & Cohen 1998; Gottwald
Emergent Reasoning Structures in Law

2001; Rodes & Pospesel 1997; Sainsbury 1991).

- **Disjunction ("or"):** A connective specifying that the truth-value of the conclusion is “true” if at least one of the truth-values of the disjunctive conditions is “true” (Copi & Cohen 1998; Gottwald 2001; Rodes & Pospesel 1997; Sainsbury 1991).

- **Defeater ("unless"):** A connective specifying that the truth-value of the conclusion is “false” if the truth-value of the defeater condition is “true” (Brewka, Dix, & Konolige 1997; Pollock 1990). The defeater condition may itself consist of either conjunctive conditions or disjunctive conditions.

- **Plausibility connectives:**
  - **Minimum ("min"):** A connective specifying that the plausibility-value of the conclusion is equal to the lowest plausibility-value possessed by any of its conditions (Gottwald 2001). The \texttt{MIN} plausibility connective is a generalized version of the \texttt{AND} truth-value connective.
  
  - **Maximum ("max"):** A connective specifying that the plausibility-value of the conclusion is equal to the highest plausibility-value possessed by any of its conditions (Gottwald 2001). The \texttt{MAX} plausibility connective is a generalized version of the \texttt{OR} truth-value connective.
  
  - **Rebut ("rebut"):** A type of defeating connective specifying that, if the rebutting condition is plausible to any degree (its plausibility-value is positive), then the plausibility-value of the conclusion is the inverse degree of implausibility (that is, its plausibility-value is negative, and to the same degree as the rebutting condition is positive) (Pollock 1990; Prakken & Sartor 1997, 2004; Prakken, Reed & Walton 2003). For example, if the rebutting condition is “highly plausible” on a seven-point ordinal scale, then the conclusion is “highly implausible” on the same scale.

- **Undercut ("undercut"):** A type of defeating connective specifying that, if the undercutting condition is plausible to any degree (its plausibility-value is positive), then the plausibility-value of the conclusion is whatever it would have been in the absence of the branch of reasoning to which the undercutting defeater is attached (Pollock 1990; Prakken & Sartor 1997, 2004; Prakken, Reed & Walton 2003). An undercutting condition defeats the line of support for the conclusion, whereas a rebutting condition defeats the conclusion itself.

- **Implication tree:** An inverted directed acyclic graph consisting of chained levels of implications, in which a condition of one implication becomes the conclusion of another implication (see Table 1 for illustration).

- **Plausibility schema:** An inverted directed acyclic graph consisting of evidentiary assertions and plausibility connectives (see Figure 1 for illustration), and which functions as a schema producing plausible inferences whenever (1) specific subjects are substituted into the schema, (2) plausibility-values are assigned to the evidentiary conditions of the schema, and (3) the plausibility-values of the evidentiary conditions, mediated by the plausibility-connective of the schema, determine a positive plausibility-value for the schema conclusion. Such an instantiated plausibility schema produces a plausible inference.

- **Inference tree:** An inverted directed acyclic graph consisting of (1) the ultimate conclusion at the top; (2) an implication tree immediately supporting that ultimate conclusion; (3) terminal propositions in each branch of the implication tree, which are supported in turn only by evidentiary assertions; and (4) lower levels of branches (below the terminal propositions) consisting of plausible inferences (instantiated plausibility schemas and perhaps additional evidentiary assertions). See Figure 2 for illustration.
Emergent Reasoning Structures in Law

Figure 2. Illustration of a Partial Inference Tree in Decision Apprentice™ Applying Tort Rules for Battery

Using the Default-Logic Framework to Model Two Legal Reasoning Structures

The D-L Framework provides the tools for modeling, in any particular legal case, the reasoning that warrants the legal findings, decisions, and actions in that case. The D-L model for the complete reasoning is an inference tree. As discussed above, an inference tree typically has at least two major regions: an implication tree near the top, directly supporting the ultimate conclusion, and plausible inferences below the terminal propositions of the implication tree. Figure 2 illustrates the general structure of an inference tree. The two sub-sections that follow discuss the two major regions of an inference tree – rule-based deductions and evidence evaluation.

Implication Trees As Modeling Systems of Rule-based Deductions in Law

The upper portion of any inference tree is an implication tree, which models all of the implications or lines of reasoning to the ultimate conclusion that are acceptable under the applicable legal rules. The ultimate conclusion at the top is the root node of an inverted “tree” structure because lower-level conditions never depend for their truth-values on a higher-level proposition in the same branch. Implication trees branch downward and outward from a single root conclusion. For example, the rules of tort law for battery, which can justify a court judgment that the defendant must pay damages, can be modeled as one large implication tree that begins as shown in Figure 2. The legal interpretation of this tree is that “the defendant is liable to the plaintiff for battery” (conclusion) if (1) “the defendant performed a voluntary act,” (2) “the defendant acted intending to cause a harmful or offensive contact with a person,” and (3) “the defendant’s act caused a harmful or offensive contact with the plaintiff,” unless this line of reasoning is defeated because “the defendant was privileged to perform the action,” which would be true if either “the defendant acted reasonably in making a lawful arrest” or “the defendant acted reasonably in self-defense against intentionally inflicted bodily harm” (American Law Institute 1966; Dobbs 2000). In each branch of an implication tree, the conditions of the last rule in that branch are the “terminal propositions” of the rules. In Figure 2, these are the five last propositional shapes (those with solid lines) in the branches. The truth-value of a terminal proposition can be determined to be either “true” or “false” only by stipulation of the parties, by certain types of decisions or rulings by the presiding legal official, or by an evaluation.
of the evidence by the factfinder. The terminal propositions of an implication tree identify all of the factual issues that are relevant to warranting the ultimate conclusion. The implication tree therefore constrains the evidence and factfinding in the case to what is relevant to deciding the truth-values of the terminal propositions.

**Plausibility Schemas as Modeling Patterns of Evidence Evaluation**

When decision-making begins in a particular legal case, the truth-values of all of the propositions within the applicable implication tree are “undecided.” Evidence evaluation is the process of using evidence to determine whether the truth-values of particular terminal propositions should change from “undecided” to either “true” or “false.” Reasoned decision-making involves: producing evidence for the legal record that is relevant to proving one or more of the terminal propositions of the implication tree; organizing that evidence into plausible inferences using plausibility schemas; attaching the schematized evidence to the appropriate terminal propositions; evaluating the plausibility-values of the evidentiary assertions; and using those plausibility-values to assign new truth-values to terminal propositions. The logical connectives can then use those truth-values to propagate truth-values up the implication tree to determine the truth-value of the ultimate conclusion at the top. The topics discussed in this sub-section of the chapter are: the evaluation of the plausibility of single evidentiary assertions, the use of plausibility schemas to organize evidentiary assertions and to make plausible inferences, and the use of instantiated plausibility schemas to determine the truth-value of a terminal proposition.

In a typical legal case, the parties produce witnesses, documents, and other evidence. The witnesses and documents then provide evidentiary assertions “for the legal record,” which constitute the bulk of the evidence. The factfinder formulates other evidentiary assertions – for example, in describing the behavior of a witness or in characterizing the results of a medical chart or other exhibit. When evaluating the plausibility of an evidentiary assertion, an agent selects a suitable plausibility scale and assigns a plausibility-value from that scale to the evidentiary assertion. Choosing the best plausibility scale to employ for evaluating any particular evidentiary assertion depends upon the pragmatic context – that is, upon the precision needed in the content and upon the potential for error that is acceptable in assessing plausibility (Walker 2007a). For example, some legal cases might require only a low degree of precision (e.g., measurements of length in inches) and accept even a moderate degree of plausibility (allowing a significant potential for error), with the result that even a single measurement with an ordinary ruler will yield acceptably accurate values. Other cases, by contrast, might require a high degree of precision (e.g., measurements of length in microns) and a high level of quantitative plausibility (e.g., 99.99% confidence that the measurement is accurate to within 2 microns). In general, as the level of required precision increases, the potential for error inherent in assessing plausibility for measurements with that precision also tends to increase. In addition, it often costs some amount of resources to produce additional evidence in an attempt to make the conclusion acceptably plausible. A reasonable decision-maker would therefore use plausibility scales that achieve the least-cost combination of precision and degree of plausibility that will yield acceptably accurate results in the pragmatic context.

The factfinder next organizes individual evidentiary assertions into patterns of reasoning relevant to proving the terminal propositions in the case, using what the D-L Framework calls “plausibility schemas.” Plausibility schemas are general patterns of evidentiary reasoning that presumptively warrant plausible inferences, by producing lines of default inference that are plausible but subject to revision. Such schemas also allow the factfinder to strike the appropriate pragmatic balance of acceptable uncertainty. Plausibility schemas consist of evidentiary assertions and plausibility connectives. An evidentiary assertion is a proposition whose active value in a line of reasoning is its plausibility-value (see the ontology above). Plausibility connectives are logical operators that determine the plausibility-value of the assertion that is the schema conclusion as a function of the plausibility-values of the assertions that form the evidentiary conditions of the schema. Four plausibility connectives that occur repeatedly
Emergent Reasoning Structures in Law

in the patterns of reasoning found in legal cases are \textsc{min}, \textsc{max}, \textsc{rebut} and \textsc{undercut} (defined in the ontology above).

One problem in the operation of plausibility schemas is that factfinding agents may adopt different plausibility scales for evaluating different evidentiary assertions. When this occurs, there must be a rule for operating on a mixture of plausibility scales – for example, where one assertion has a plausibility-value on a seven-point ordinal scale and another in the same plausibility schema has a quantitative value on the real-number scale. For the plausibility connectives of minimum (\textsc{min}) and maximum (\textsc{max}), the factfinding agent must determine whether a particular value on one scale is lower or higher than a value on another scale. Given such a combined ordering of possible plausibility-values, however, the plausibility-value of the schema conclusion can be determined on the plausibility scale of the critical evidentiary assertion – that is, for \textsc{min}, the evidentiary assertion with the lowest plausibility-value, and for \textsc{max}, the evidentiary assertion with the highest plausibility-value.

By contrast, the two defeater plausibility connectives, \textsc{rebut} and \textsc{undercut}, take single assertions as rebutting or undercutting defeaters, and so do not have this multiple-scale problem (although \textsc{min} or \textsc{max} connectives under the defeating assertions may have this problem). In the case of a plausibility rebutter, if the rebutting assertion has a positive plausibility-value, then the connective \textsc{rebut} assigns to the schema conclusion the degree of plausibility that is the inverse to the plausibility-value of the rebutting assertion. That is, as the degree of plausibility of the rebutting assertion increases, the degree of plausibility of the conclusion decreases (alternatively, the degree of implausibility of the conclusion increases). For example, on the seven-point plausibility scale above, if the plausibility-value of the rebutting assertion is “highly plausible,” then the plausibility-value of the schema conclusion would be “highly implausible.” On a plausibility scale of mathematical probability, if the rebutter’s plausibility-value is 0.56, then the conclusion’s plausibility-value would be 0.44 (1 – 0.56).

In the case of a plausibility undercutter, if the undercutting assertion has a positive plausibility-value, then the connective \textsc{undercut} assigns to the schema conclusion the degree of plausibility that it would have had in the absence of the line of reasoning that is undercut. An undercutter connective can be useful in capturing the logic of an assertion that defeats only one condition of a set of conditions. As illustrated in the schema in Figure 1, a positive undercutting assertion would simply take out of play the right-hand branch below the \textsc{min} connect-
 Emergent Reasoning Structures in Law

tive of the schema, leaving the plausibility-value of the left-hand assertion under the $\min$ connective to determine the plausibility-value of the schema conclusion.

An example of a plausibility schema commonly found in actual reasoning is the “statistical syllogism” or “direct-inference” schema, which models one type of presumptive reasoning about a definite subject or specific individual (Walker 2007a, 2007c; Kyburg 1983; Levi 1977, 1981; Pollock 1990; Salmon 1973). Examples of such conclusions are “the tire that caused the accident had a defect” and “the claimant contracted pneumoconiosis,” where “the tire” and “the claimant” are definite subjects (for pertinent legal cases, see Kumho Tire Co. Ltd. v. Carmichael, 526 U.S. 137 (1999), and Director, Office of Workers’ Compensation Programs, Department of Labor v. Greenwich Collieries, 512 U.S. 267 (1994)). A D-L diagram for the plausibility schema modeling the statistical syllogism is shown in Figure 3 (Walker 2007c, p. 11). The plausibility connective $\min$ joining the evidentiary conditions of the schema assigns a plausibility-value to the schema conclusion that is equal to the plausibility-value of the least plausible of the three joined assertions. The three conditions state the evidentiary assertions that together render the conclusion plausible. The first evidentiary assertion (from the left) is a generalization asserting that most objects in Category P are also in Category Q. The second evidentiary assertion is that the specific object that is the definite subject of the conclusion (O) is in Category P. The third evidentiary assertion states that the objects in Category P adequately represent Object O, with respect to a sufficient number of variables (attributes) that are predictive of being in Category Q. Thus, a factfinder using this pattern of reasoning to warrant assigning a plausibility-value to such a conclusion must substitute specific values for the three logical subjects (“Category P,” “Category Q,” and “Object O”) and then assign plausibility-values to each of the three evidentiary conditions of the inference. Subject substitution creates an instance of the schema (an instantiated schema). In addition, assigning plausibility-values that generate a positive plausibility-value for the schema conclusion creates a plausible inference.

One component of many plausibility schemas is an assertion that states a generalization (Chierchia and McConnell-Ginet 2000; Copi and Cohen 1998; Kadane and Schum 1996; Rodes and Pospesel 1997; Schum 1994; Toulmin 1958). A generalization is an assertion stating that its description is true of some of the subjects in the class to which it refers (a proper subset of the referenced subject class), but does not assert that it is true of all subjects in the class. Examples of generalizations are: “most witnesses testifying under oath tell the truth”; “one-third of Americans are overweight”; and “60% of the test group in the study developed the disease.” These three generalizations have the following logical forms (respectively): “most Ps are Qs”; “X/Y of Ps are Qs”; and “X% of the members of group P are members of group Q.” Logicians call group P the “reference class” or “reference group” for the generalization (Kyburg 1990). Two logical attributes of a generalization that can affect its plausibility-value are its degree of quantification and any modal hedge employed. Generalizations imply or explicitly assert a degree of quantification over the reference class — that is, they assert what portion of members of class P is also included in class Q. Moreover, generalizations often contain an explicit modal “hedge” that qualifies the entire assertion. Examples of modal hedges are expressions of frequency (e.g., “sometimes” or “often”), typicality (e.g., “typically” or “normally”), temporal limitation (e.g., “in the past” or “at least for the immediate future”), or degree of confidence of the speaker (e.g., “perhaps” or “almost certainly”). Generalizations may be warranted by scientific, technical or other specialized knowledge, or they may derive from personal experience or “common sense.”

Plausibility schemas play an important role in integrating expert evidentiary assertions with non-expert evidentiary assertions into a single line of evidentiary reasoning. For example, the generalization in the statistical-syllogism schema may be supported by either expert or non-expert evidence — statistical or other scientific evidence in one case, but only scattered anecdotal evidence in another case. Regardless of the nature of the support for the generalization, the evidentiary assertion that the definite subject is in Category P may be based upon non-expert eyewitness testimony. The plausibility connective of the schema specifies the algorithm for assigning a plausibility-value to the
schema conclusion, regardless of the mixture of expert and non-expert evidence supporting that conclusion. For example, an instantiation of the statistical-syllogism plausibility schema shown in Figure 3 might be the result of a scientific study and have a high level of plausibility, while there may be substantial uncertainty about whether Object O is in fact in Category P. In such a case, the low plausibility-value for the second evidentiary assertion might be the critical minimum value for the instantiated schema, resulting in a correspondingly low plausibility-value for the schema conclusion. The evaluating agent might then consider several strategies for increasing the plausibility-value of that second evidentiary assertion. Alternatively, the agent might rely on a different line of reasoning altogether, using different schemas and evidence, thus bypassing this weak statistical-syllogism line of reasoning.

After the factfinder uses the available evidentiary assertions to instantiate a plausibility schema, the factfinder uses the instantiated schema to determine the truth-value of a terminal proposition in the implication tree. The two primary factors in selecting which plausibility schema to use in reasoning to a particular terminal proposition are (1) the logical form of the terminal proposition and (2) the nature of the evidence available in the case. For example, whether the terminal proposition is a generalization about a group or a proposition about a specific individual will determine what kind of schema conclusion is allowed. Second, different schemas may require different kinds of evidentiary assertions as input. Some schemas might require evidence that is scientific and statistical, while others might not. The agent evaluating the evidence selects a schema that fits the terminal proposition and the evidence in the particular case. In the Legal Apprentice™ software, the user “attaches” the instantiated schema to the terminal proposition to which it is relevant, thus extending the branch of the inference tree out of the rule-based implication tree and into the evidence-evaluation region. The schema instantiated with evidence is specific to the particular case, whereas the implication tree and the plausibility schemas themselves are generic structures for all cases within the knowledge domain.

Finally, in order for an instantiated plausibility schema to provide an inference from plausible evidence to a decision about the ultimate issue at the top of the implication tree, there must be an algorithm for determining the truth-value of a terminal proposition as a function of the plausibility-value of the schematized evidence attached to that proposition. Law calls this rule the applicable “standard of proof” (James, Hazard, and Leubsdorf 1992; Walker 1996). For example, the standard of proof for most issues of fact in civil cases is preponderance of the evidence. Under this rule, if the schematized evidence evaluates as having any plausibility-value other than “undecided,” then the preponderance rule assigns the corresponding truth-value to the terminal proposition – that is, it assigns the value “true” to the terminal proposition if the schema evaluates the attached evidence as plausible to any degree, and assigns the value “false” to the terminal proposition if the schema evaluates the attached evidence as implausible to any degree. Standards of proof are the links between the output of schematized, evaluated evidence and the input to an implication tree.

The branches of an instantiated plausibility schema can themselves generate chains of instantiated plausibility schemas, with the evidentiary conditions of a higher-level schema becoming the conclusions of lower-level plausibility schemas. For example, the second evidentiary assertion of the statistical-syllogism schema in Figure 3 is itself an assertion categorizing a definite subject, so in a particular case such an assertion could become the conclusion of an additional statistical-syllogism schema. At some point in any particular branch, of course, the evaluating agent must stipulate plausibility-values for evidentiary assertions – using intuition (human agents), default values (human and non-human agents), sensitivity analysis (all agents), or some other method.

Modeling Second-Order Reasoning About Rules and Evidence

While many instances of legal reasoning employ “substantive” rules of law and the relevant evidence to reach ultimate conclusions, other instances consist of second-order reasoning about which rules, evidentiary assertions or plausible inferences are allowed. Such second-order reasoning in law is
Emergent Reasoning Structures in Law

also rule-based reasoning, but it generally employs “process rules.” Process rules in law are traditionally divided into rules of procedure and rules of evidence. Rules of procedure govern the dynamics and timing of default reasoning by authorizing particular procedural decisions under certain conditions. For example, early in a civil proceeding a defendant may move to dismiss the case for lack of jurisdiction; any party may move for summary judgment before trial based on depositions and affidavits; or a party may move for a directed verdict during a trial, based upon the testimony introduced to that point in time (Federal Rules of Civil Procedure; James, Hazard, and Leubsdorf 1992). The presiding official must decide whether to grant a procedural motion or deny it. Implication trees can model the legal rules that govern such decisions, and plausibility schemas can organize the relevant evidence in a particular case.

Evidentiary process rules govern the process of evaluating evidence and making findings about terminal propositions. Evidentiary decisions (rulings on motions) might apply: rules about admissibility (excluding some relevant evidence from the case altogether, or prohibiting its attachment to certain terminal propositions); rules about relevancy (relating particular evidentiary assertions to particular terminal propositions); rules about sufficiency of evidence (deciding whether the totality of evidence attached to a terminal proposition can warrant a finding that the proposition is true); standards of proof (establishing the threshold degree of plausibility required to find a terminal proposition to be true); and rules allocating the burden of persuasion (determining what finding to make when the attached evidence evaluates precisely on the threshold required by the standard of proof). These evidentiary rules govern the presiding official’s decisions about the process of evidentiary evaluation in a particular case. An example is the rule admitting an expert opinion into evidence only if it is “scientific, technical, or other specialized knowledge” and it “will assist the trier of fact” (Federal Rule of Evidence 702; Daubert v. Merrell Dow Pharmaceuticals, Inc., 509 U.S. 579 (1993); General Electric Co. v. Joiner, 522 U.S. 136 (1997); Kumho Tire Co. v. Carmichael, 526 U.S. 137 (1999)). Another example is a ruling that the relevant evidence is legally insufficient to warrant a finding of fact by the factfinder. Such a ruling can directly determine, “as a matter of law,” the truth-value of a terminal proposition in an implication tree. Implication trees can model such evidentiary rules, and plausibility schemas can help warrant their application in particular cases.

Process rules therefore apply the rule of law to the process of using implication trees and plausibility schemas in a particular case. More generally, they are rules that govern the dynamics of default reasoning within multiagent systems. Process rules are particularly important in coordinating multiple independent agents to achieve consistent, fair and efficient decision processes. Different participants can play different roles in rule application, evidence production, evidence evaluation, and other decision-making tasks, yet the process rules coordinate and regulate the dynamic process. Legal proceedings consist of many points at which different participants may make different decisions, depending upon the process rules, substantive legal rules and the available evidence. In judicial litigation, for example, the parties, trial judge, jury and appellate court have distinct roles to play, and in administrative rulemakings, the public commenters, expert advisory groups, regulators and reviewing courts have their own distinct roles. Presiding officials oversee the factfinding process by making decisions that are themselves governed by legal rules and the evidence in the record, while reviewing courts oversee the decision-making discretion of the presiding trial official.

A key feature of the D-L Framework, and a key insight into the emergence of reasoning structures, is that no new types of logical structures are required to model legal process rules or their operation. The D-L Framework integrates substantive and process reasoning by attaching process implication trees as branches of the main implication tree in a legal proceeding. For example, a jurisdictional requirement, and its associated implication tree, would be a high-level conjunctive branch for any implication tree for a valid judicial judgment. On the other hand, an evidentiary requirement, and its implication tree, might be a defeater branch connected near a terminal proposition of the main implication tree. This means that the D-L Framework can capture the domain knowledge for evolution and coordination using the same ontology that captures substantive legal rules and the factfinding in particular cases.
THE EMERGENCE OF REASONING STRUCTURES IN LAW

The regime of the rule of law, with its insistence on transparent and documented reasoning, responds to the multiplicity and diversity of legal cases by creating useful logical structures and adapting them to the legal problems they are designed to solve. A system of rule-based deductions captured by an implication tree represents one type of emergent structure. The plausibility schemas recognized in law are such structures as well. Such structures promote consistency among independent legal decision-makers in different cases, while also promoting the principled and consistent evaluation of evidence specific to those cases. But law is not only a domain that happens to have emergent reasoning structures – it is a domain in which these emergent structures promote the emergence and evolution of other structures. In law, the emergence of reasoning structures is not merely a by-product, but rather an intentional product of the system. The reason for this is once again the rule of law. A fundamental value within law is its ability to adapt its rules to new types of situations, and to adapt them in a principled rather than haphazard way. The common law is a particularly good example of a system designed to produce gradual adaptation to new problems through the emergence of new rules and other logical structures. In law, as in ordinary life, the most appropriate new structures generally evolve gradually from successful decisions in past cases.

The adherence to process rules promotes the evolution of new implication trees and new plausibility schemas. Legal systems use process rules to evolve new legal rules from past legal decisions, and to evolve new plausibility schemas from past evaluations of evidence. For example, a motion for summary judgment in a particular civil case might present a novel factual situation, and the arguments by the attorneys might lead the court to decide the motion by instituting a new substantive rule or a new process rule. Such a motion can also lead to a judicial ruling that the available evidence is insufficient for a reasonable factfinder to make a particular finding of fact – a ruling that other courts can apply in similar circumstances. Over time, such rulings can result in the emergence of new plausibility schemas for organizing such evidence. Process rules therefore play an important role in creating emergent reasoning structures in law.

When a reasoned decision is made to adopt a new legal rule (i.e., to modify an implication tree), the reasoning balances “policy rationales” for and against a rule change. Policy rationales can be either epistemic or non-epistemic (Walker 2003, 2004). Epistemic policies have the objective of increasing the accuracy of factual findings, or increasing the number of accurate findings, as well as improving the evidentiary warrant for findings and decisions. An example of an epistemic policy is allocating the burden of producing evidence to the party that is in the best position to produce that type of evidence. Non-epistemic policies pursue non-epistemic objectives (e.g., administrative efficiency and fairness to the parties). The reasoning that justifies a particular rule change ideally balances all of the epistemic and non-epistemic policies that are relevant to the proposed rule.

When a reasoned decision is made to adopt a new plausibility schema, the reasoning also balances the epistemic objective against the appropriate non-epistemic objectives. Plausibility schemas are designed to warrant default inferences against the appropriate non-epistemic objectives. Plausibility schemas are designed to warrant default inferences against the appropriate non-epistemic objectives. A major strategy for designing a plausibility schema is to develop a “theory of uncertainty” for the type of inference involved (Walker 2001). A theory of uncertainty explains how the available evidence could be plausible but the conclusion could still be false (or in the case of a plausible defeater, how the conclusion could still be true). It identifies the possible sources of error inherent in the type of inference, and analyzes the sources, types, and degrees of uncertainty associated with drawing the conclusion. In examining the inherent uncertainty, however, a theory of uncertainty also explains why it is reasonable to draw the conclusion in a tentative way, even on the basis of incomplete evidence. Every plausibility schema, therefore, reflects a theory of uncertainty about why the schema’s inference is defeasible yet acceptable in the pragmatic legal context. The D-L Framework can assist the evolutionary process by clearly identifying the patterns of reasoning that actually occur in legal cases.

An important advantage of the D-L Framework is the potential it offers to involve non-human au-
Emergent Reasoning Structures in Law

In the D-L Framework, a complete inference tree for the reasoning in a particular legal case consists of an implication tree that models all of the applicable substantive and process rules, together with the schematized evidentiary assertions attached to the terminal propositions of that implication tree. The syntax and Semantics of this framework allow the automation of key tasks, and the emergence of dynamic structures for integrating human and non-human agents. Moreover, it is the logical structure of legal reasoning itself, and not any particular set of rules within the legal knowledge domain, that creates this evolutionary mechanism. This means that the evolutionary mechanism applies to domestic, foreign and international legal systems; that non-human autonomous agents can participate in this evolution, interacting with human agents; and that similar reasoning structures can operate in many knowledge domains other than law.

FUTURE RESEARCH DIRECTIONS

The D-L Framework provides a useful, standardized format for empirical research into the reasoning involved in legal cases. Such research has obvious advantages for substantive legal research. The research gains may be just as significant, moreover, for discovering logical structures that allow the interaction of human and non-human agents in evolving reasoning structures in all domains with characteristics similar to law. Several directions for such research present themselves. Research is needed on the reasoning that balances the epistemic objective against non-epistemic objectives to arrive at an appropriate new rule. Such research may discover patterns of rule development that might prove useful in many domains. Research is also needed on the variety of plausibility schemas that are used in different areas of law. Such research would clarify the patterns of default reasoning that human agents have considered valid, and may suggest new structures for developing new schemas. Finally, research is important on the process structures that make emergence and evolution possible. Legal reasoning represents a concerted human effort at principled, adaptive decision-making in the face of incomplete evidence and new situations – a type of
Emergent Reasoning Structures in Law

problem that confronts society in many domains. In each of these directions, the task is to discover empirically what structures have evolved, and to model and automate those structures to the extent possible, so that emergence and evolution can be more efficient in the future.

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Emergent Reasoning Structures in Law


Emergent Reasoning Structures in Law


**ADDITIONAL READING**


